RF Coupler and Tuner Design for the Rare Isotope Accelerator Superconducting Cavities

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Abstract

The low-beta cavities proposed for the Rare Isotope Accelerator (RIA) driver linac require RF power couplers and both slow and fast tuning systems. This paper discusses several methods for tuning and phase stabilization, the use of passive vibration damping, and a variable power coupler suitable for all the low beta cavities required for RIA. Because of the relatively small beam loading that is characteristic of the RIA accelerator, the loaded cavity bandwidth is too narrow to accommodate possible microphonic-induced frequency noise, and a fast-tuning system is needed to phase-stabilize the low-beta cavities. There are several possible choices of fast-tuning system. For cavities operating at and below 150 MHz, the variable reactance tuner which has been developed for the existing ATLAS accelerator has ample tuning range, is cost-effective, and has demonstrated high reliability over many millions of unit-hours of operation. We also discuss the design of a variable power coupler for CW operation at 20 kW, a prototype of which has successfully operated in tests with a 345 MHz double-spoke cavity.

RF Power Coupler

The RF power coupler for the low to medium beta cavities is in a class that does not presently exist. As determined by the beam loading power and the power for phase stabilization, the RF power coupler should be capable of delivering 20kW CW power. It must span a frequency range from 48 to 350 MHz. To achieve the high accelerating gradients required for RIA, it has been demonstrated that interior cavity cleanliness plays a large role. Therefore, any probe that is inserted into the cavity must be capable of maintaining high cleanliness standards. This mandates a design that provides separate vacuum systems for the cavity interior and the cryostat insulating vacuum. The coupler should be adjustable from the outside and provide thermal isolation from 80k to 4.5k.

At ANL in collaboration with Porcellato (INFN Legnaro) a prototype coupler has been designed to meet the required goals. (Figure 1.)

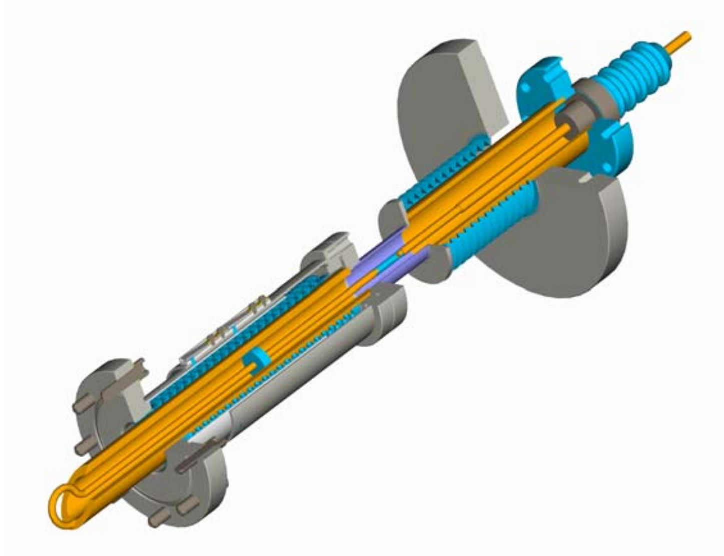

Figure 1 Prototype 20 kW RF coupling probe

Design version one has been tested on the ANL 350 MHZ double-spoke cavity. It has operated at 7kW pulsed power, has a 3 inch stroke and is adjustable via a stepping motor. This 1st version design will be used to phase stabilize the double-spoke cavity operating in realistic conditions. A second version is under construction.

Slow Tuners

Several successful methods have been employed at many facilities to compensate for slow frequency drifts due to changes in the helium system pressure: They all use a mechanical force to deform the cavity. Some the methods include stepping motor and compression screws, ATLAS uses a pneumatic system operated with helium gas and a bellows to compress the cavity wall, and under development is a pre-loaded magneto-strictive tuner.

Some form of any of the existing methods should be adaptable to RIA.

Phase Stabilization

Beam loading for the low and medium beta RIA cavities will be on the order of 500 to 1500 watts resulting in bandwidths of 50 to 250 Hz. Microphonic-induced frequency noise in most of the cavities is beyond the beam-loaded bandwidth. Phase stabilization is not a fundamental technical problem for drift-tube cavities, and presently there are three methods available for phase stabilization. They are: over-coupling, electro-mechanical tuners and a reactive tuner. (ATLAS) [1] All three methods or a combination of methods will most likely be used for RIA.

Electro-mechanical tuners

Electro-mechanical tuners are attractive for the 345 (two-cell and three-cell spoke) and 172.5 MHz (half-wave) cavities. The mechanical design of these cavities is rigid, the calculated mechanical vibration modes are high and microphonic noise is relatively small as compared to other cavity geometries.

Microphonics measurements on the ANL β=0.4 two-cell spoke cavity have been performed, many at high fields using a new “cavity resonance monitor” device developed in collaboration with JLAB. Tests on a cold two-cell spoke are the first ever on a multi-cell spoke geometry. The design is essentially a production model with an integral stainless steel housing to hold the liquid helium bath. [2] The results have shown that the dominant mechanical vibration frequency is about 600Hz. The microphonic induced frequency noise is on the order of 2 to 5Hz rms. Developments to phase stabilize this cavity using a piezo-electric tuner is underway in collaboration with Delayan (TJNAF), Simrock (DESY), and Rusnak (LLNL). Also Energen (Joshi), as part of an SBRI grant, will provide a magneto-restrictive tuner to ANL.

The overwhelming advantage of electro-mechanical tuners is that it is not affected by the stored energy of the cavity. There is no RF power dissipation in the electro-mechanical tuner.

Over-coupling

Increasing the cavity bandwidth by over-coupling the drive probe is also an option. The amount of RF power required for this method is determined by beam loading and the amplitude of the microphonic-induced noise. This second factor is difficult to predict. ANL has measurements on the 350 MHz two-cell spoke cavity and years of experience with a 48.5 MHz cavity, which is very similar to the RIA 57.5 MHz class cavity. For the 57.5 MHz cavity we can expect tuning windows to be on the order of 100 to 200 Hz. Given these parameters, Table 1 shows the power requirements to phase stabilize by over-coupling.

Freq (MHz)	Beta	Emax	Beam Power	Tuning Window (Hz) 50	100 Over-coupling RF Power (W)	200	ATLAS Fast Tuner Reactive Pk-Pk Pwr 200Hz Window	Real RF Power
57.5	0.02	20	538	574	1149	2298	9192	92
57.5	0.03	20	663	1162	2324	4647	18589	186
57.5	0.06	20	557	1538	3075	6151	24602	246
115	0.15	20	794	2168	4337	8674	34696	347
172.5	0.26	20	1052	5120	10240	20480		
345	0.38	20	1150	1615	3229	6459		
805	0.47	27.5	2161	6964	13927	27855		
805	0.61	27.5	3530	10670	21340	42681		
805	0.81	27.5	5800	16636	33272	66544		
345	0.50	27.5	3175	11366	22732	45463		
345	0.63	27.5	3819	15614	31228	62455		

Table 1 Shows the RF power required for the beam and tuning windows of 50, 100 and 200 Hz and for the low-beta cavities the real dissipated power using the variable reactance fast tuner to phase stabilize.

Mechanical Damping

For the quarter-wave cavity design a passive damping device, developed by Facco (INFN Legnaro) [3], can be installed to reduce the amount of mechanical vibration. This reduction will proportionately lower the amount of RF Power needed to phase stabilize the cavity. At ANL a modified design of the vibration damper was installed in three low beta cavities. The results are shown in figure 2.

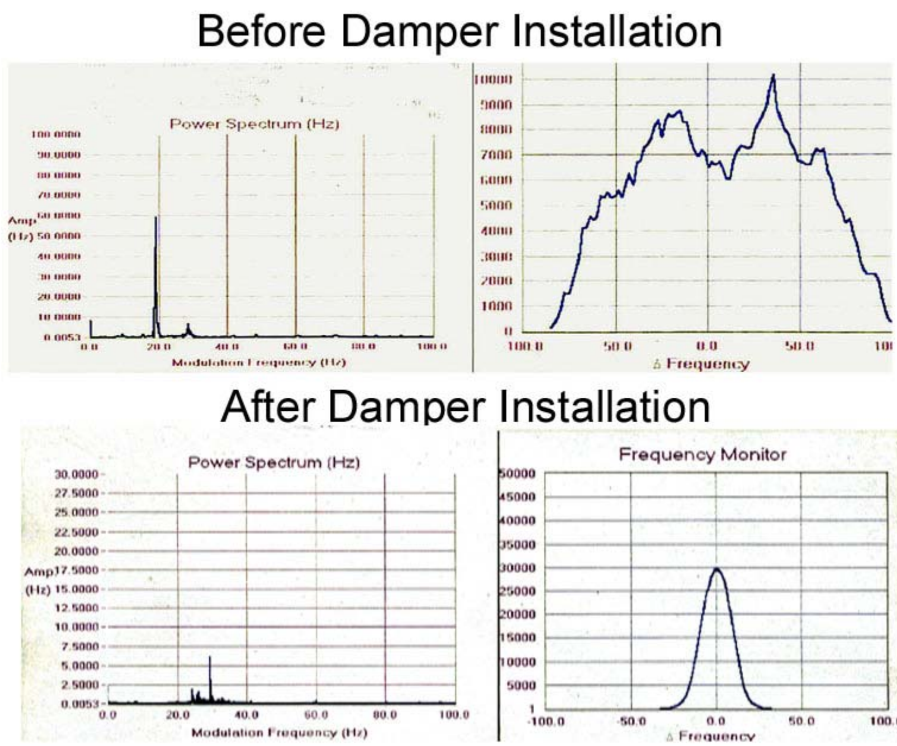

Figure 2 demonstrates about a factor of four reduction of the tuning window

Reactive Tuner

A fast tuner based on 80k PIN diode switching technology is in use at ATLAS. It has been used to phase stabilize cavities at ATLAS from 48 to 150 MHz. This technology is directly transferable to the RIA cavities from 57.5 MHz to 115 MHz**.** The present fast tuner design has successfully switched 35kVAR. To have an equivalent control capability using an over- coupled system it would require a 9 kW RF source.

The fast tuner in its present state has been proven at ATLAS with more than 1.3 million resonator hours of operation over the past seven years. Complete statistics show that over that same time period there has been only a total of 84 hours lost time due to the fast tuner system.

The majority of the power to operate the fast tuner is dissipated into liquid nitrogen. For typical tuning windows of about 200 Hz, about 1% of the Pk to Pk reactive power is dissipated into LN2 and approximately 2 watts of power from the fast tuners is dissipated into the helium system.

Freq (MHz)	Beta	Emax	Fast Tuner Reactive Pk-Pk Pwr 200Hz	Real Pwr into LN2 (W)	Beam Power
57.5	0.02	20	9192	92	538
57.5	0.03	20	18589	186	663
57.5	0.06	20	24602	246	557
115	0.15	20	34696	347	794

The cost of the entire system fast tuner system is listed below.

80k Mechanical Unit	**$2.7k**
Electronic Units	
Pulser	$2.2k
Power supplies	$0.630k
RF control section	$1.25k
Assembly Cost	$0.90k
Total	**$7.68k**
LN2 Operating Cost	**$0.19 / cavity hr.**

Conclusion

Realistic tests on final form RIA cavities are necessary to get real data on microphonics and to make cost effective system design choices. The next prototype RF couple is in progress at ANL and tests will be done on completion. The present slow tuning technology is transferable to RIA. Also there is a choice of several methods for phase stabilizing cavities. The most appropriate method needs to be determined for each class of cavity.

Development on electro-mechanical fast tuners is started and testing will proceed as scheduled.

For the RIA low-beta cavities, the PIN diode reactive fast tuner is a proven, highly reliable system.

References:

[1] N.Added et al, Proc. of the 16th International Linear Accelerator Conference (1992)

[2] M. P. Kelly at al,

[3} A. Facco et al, 9th Workshop on RF Superconductivity (1999) Vol 1 pp 309-311